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(54) IMPROVEMENTS RELATING TO APPARATUS FOR ENCODING IMAGES

(71) We, INTERNATIONAL BUSINESS MACHINES CORPORATION, a Corporation organized and existing under the laws of the State of New York in the United States of America, of Armonk, New York 10504, United States of America do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:–

This invention relates to apparatus for encoding an image, for example, before it is stored, displayed or transmitted. When an image, particularly one containing pictorial information, is digitized, it is split into a number of picture elements (or pels). In a black and white image, each pel can be represented by a binary "1" or a binary "0" determined by whether that particular pel is present or not (or *vice versa*). However, if the image contains a grey scale, more than one bit per pel is normally required: the number of bits needed depends on the number of grey levels.

The Complete Specification of our co-pending Application for Letters Patent (50,744/75) (Serial No. 1,497,587) describes a technique for reducing the number of bits needed to represent, for example, a grey-scale image. Briefly the grey-scale image can be represented by a delta-coded sequence which is first subjected to a prediction algorithm: error signals are generated when an actual bit in the sequence is different from the predicted bit. These error signals are then run-length encoded. The amount of compression is determined mainly by the accuracy of the predictor.

The present specification describes an alternative technique for coding a grey-scale image.

The problem of printing a grey-scale image with essentially a binary technique has been solved in the printing art with half-tone printing which uses the fact that at a sufficient distance small digitized pattern elements are not recognized as such by the human eye but are rather perceived as a continuous grey tone integrating several of these pattern elements.

Generally, a half-tone image is formed by appertaining the grey value of image areas and associating this analogue grey value with an interval of the grey value scale (subdivided into p intervals). The different shades of grey are printed by varying the size of printed dot. The higher the grey value, the greater the diameter of each dot in that area of the image. The number of dots in each area is chosen in accordance with the printing quality required.

In accordance with the present invention, apparatus for encoding an image comprises means for raster scaning the image, means for measuring the grey value of each raster point and assigning to each raster point one of a plurality of digital grey values, means for representing each raster point as a matrix of bits having a bit pattern in accordance with the digital grey value assigned to that raster point, and means for run-length encoding the bit patterns of adjacent scan points.

Where the image is subsequently printed (or displayed) it will be different to the conventional half-tone image described above in which different levels of grey are represented by dots of different size. An image encoded in accordance with the present invention has, within each scanned raster point, a bit pattern which depends on the particular grey level: the reconstituted image will be formed by a number of dots in accordance with the bit pattern, the size of dots remaining constant from scanned raster point to scanned raster point. Clearly the point (or display) raster is finer than the original scan raster.

Preferably the dots (or image elements) within each scanned raster point are so

positioned to increase the probability that dots (image elements) in adjacent raster points can be efficiently run-length-encoded.

In the embodiments to be described, the grey value of each scanned raster point is determined and associated with an interval of the grey value scale subdivided into $p + 1$ levels, each scanned raster point being represented by $(\frac{p}{2})^2$ bits arranged in matrix shape: the number of similar value bits is determined line-by-line or column-by-column and run length encoded.

For pure text images it is advantageous to optimize all run lengths possible by means of a logarithmic code. In comparison with pure text information, graphical images such as weather charts or line drawings, whose run lengths do not include any distinct maxima, are advantageously code optimized by means of a linear code.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:–

FIGURE 1 is a schematic showing how a matrix of individual image points can be divided into black and white image elements to give a grey value scale in accordance with a first pattern,

FIGURE 2 is a schematic showing how a matrix of individual image points can be divided into black and white image elements in accordance with a second pattern,

FIGURE 3 is a diagram showing the probability distribution P(RL) for various run lengths (RL) of text information,

FIGURE 4 is a diagram showing the probability distribution P(RL) for the various run lengths of line drawings,

FIGURE 5 represents a simplification of the matrix of individual image elements in accordance with FIGURE 2,

FIGURE 6 is a schematic of a circuit for determining the black and white image element pairs of FIGURE 5 from digital grey values,

FIGURES 7 and 8 illustrate run length encoding principles, and

FIGURE 9 is a block diagram showing apparatus for encoding an image.

To encode an image, it must first be divided into a number of image areas. This is done by raster scanning the image. The level of grey associated with each image area (raster point) is determined.

In the example described it is assumed that the grey value scale comprises $p + 1 = 9$ levels (white, black and 7 grey values).

Whereas previously the different grey values were represented within the image area by a black point with a variable diameter, such an image area is subdivided in accordance with the invention into individual image elements.

In accordance with FIGURE 1, this subdivision is effected in such a manner that an image area is assumed to comprise light and/or dark image elements arranged in matrix shape. The matrix consists of $(\frac{p}{2})^2 = 16$ image elements. For the various grey stages the corresponding subdivisions of the image areas into individual image elements are shown in FIGURE 1, proceeding from a black image area. The black stage and the grey stages are marked by the numbers I1 to I8. Grey stages I2 to I8 are subdivided in the decreasing order of the grey tone.

A lighter grey stone is obtained by including in the image area a greater number of white image elements. The black and white image elements for the individual grey stages are arranged to the following pattern within each area:–

1	5	4	2
3	7	8	6
6	8	7	3
2	4	5	1

The lines and columns of this pattern comprise as many digits as there are matrix-shaped image elements in the image area, namely 4 × 4 image elements. Black image elements occur for the first time in the first grey stage I8 at the points of the image element matrix marked by the digit 8. (Looking at the grey value scale from right to left, viz. I8, I7, I6 . . . I1).

In other words, the digit 8 in the pattern indicates that for the grey value stage I8 in FIGURE 1 the corresponding matrix image point element is black. For the subsequent grey value stage I7, the image point elements marked by 7 in the pattern are black, in addition to the black image point elements of stage I8. For the grey value stage I6 the image point elements marked as 6 in the pattern are additionally black, etc.

For storing a random image made up of a plurality of image areas and in which the image

areas consist of individual image elements arranged in matrix shape, it is necessary to store the image element data in black or white. To this end, storage could be effected using run length encoding known *per se*. According to this method, the number (run length) of all similar image point elements arranged adjacent each (or one above the) other would be stored beyond the boundaries of an image point. Referring to FIGURE 7, three adjacent image areas A, B and C on a raster scan line have grey values of I1, I3 and I5 respectively. The information can be stored row by row as follows:–

4,	1,	2,	2,	1,	2
8,	1,	3			
11,	1				
4,	1,	2,	3,	1,	1

The third digit row I1, 1 will be explained by way of example: in the third row of the adjacent image areas A, B and C, 11 black image elements are arranged adjacent each other (thus the digit 11), followed by a white image element (thus 11 followed by the digit 1). These digits would be stored in a computer in coded form. To reduce the storage space, the individual "runs" i.e., the number of similar adjacent image elements, subsequently referred to as run lengths, can be subjected to a probability distribution. Such code optimizations are known *per se*. As an example of coding the possible run lengths, the Huffman code optimization method may be chosen. It is assumed that at a particular image size the individual run lengths are of the order of 1 to 128. These run lengths are subjected to the Huffman probability distribution in accordance with table I.

The probability with which a particular run length RL occurs is designated as p(RL) in table I.

TABLE I

Run Length (RL)	p(RL)	Binary Code
1	0.10	011
2	0.18	001
3	0.40	1
4	0.05	000010
5	0.06	0101
6	0.10	0000
7	0.06	0100
8	0.03	00011
.	.	.
.	.	.
.	.	.
128	0.02	1000111001

According to the Huffman distribution, image element run lengths with a low probability are assigned a long code word (less frequent), whereas run lengths with a high probability are assigned a short code word. If, as shown in table I, run length 4 has a probability of 0.05, this run length is binarily coded as 00010; run length 3 having a probability of 0.40 is binarily coded as 1.

This Huffman code optimization when applied to a subdivision of the image areas in accordance with FIGURE 1 yields a compression factor of 1.4 in comparison to run length storage without code optimization.

A further improvement of the compression factor to 5.45 at the same image quality may be obtained by using an image point subdivision in accordance with FIGURE 2. Analog-

ously to FIGURE 1, this image point subdivision is effected to the pattern:–

8	8	7	7
6	6	5	5
4	4	3	3
2	2	1	1

This image point subdivision has the advantage that for adjacent image areas of differing grey levels there are, on an average, fewer but longer "runs". Thus as can be seen with reference to FIGURE 8, only the following run lengths would have to be stored for 3 adjacent image points A′, B′ and C′ having grey values I1, I3 and I5:–

12	
12	
8,	4
4,	8

A modification of the method previously described can be appropriately made for pure text print information. In the case of pure texts, the letter spacing, the typical line thickness of a particular font, the line spacing, etc., lead to an e-function type distribution of the run lengths (RL) with typical maxima superimposed as shown in FIGURE 3. Code optimization is best carried out by means of a logarithmic code in such circumstances.

An example of such a logarithmic code is shown in table II.

In the binary code each binary stage is associated with a so-called "coloured bit" to permit decoding in accordance with black and white image elements.

These coloured bits are not listed in the binary code of table II.

TABLE II

Run Length (RL)	Binary Code
1	0
2	1
3	0 0
4	0 1
5	1 0
6	1 1
7	0 0 0
8	0 0 1
9	0 1 0
10	0 1 1
11	1 0 0
12	1 0 1
13	1 1 0
14	1 1 1
15	0 0 0 0
16	0 0 0 1

In the first column the run lengths (RL) for similar image elements arranged adjacent each (or one below the) other are specified; the binary code pertaining to these run lengths appears in the second column. Four similar adjacent image elements are binarily coded as 01 and ten similar adjacent image elements as 011. Such logarithmic codes are usefully employed for code optimization if a distribution corresponding to a descending e-function with individual maxima exists.

Another code optimization may be employed for weather charts, line drawings, or the like. FIGURE 4 shows the probability distribution curve p(RL) of the run lengths (RL) for

a typical weather chart. The diagram shows a descending e-function without maxima. For code optimizing such a distribution curve a so-called linear code is particularly favourable. Table III shows an example of a linear code.

TABLE III

Run Length (RL)	Binary Code
1	0 0 1
2	0 1 0
3	0 1 1
4	1 0 0
5	1 0 1
6	1 1 0
7	1 1 1
8	0 0 0 0 0 1
9	0 0 0 0 1 0
10	0 0 0 0 1 1
11	0 0 0 1 0 0
12	0 0 0 1 0 1
13	0 0 0 1 1 0
14	0 0 0 1 1 1
15	0 0 0 0 0 0 0 0
16	0 0 0 0 0 0 0 1

The run lengths (RL) for similar image elements arranged adjacent each (or one below the) other are specified in the first column, whereas the second column contains the codes pertaining to these run lengths. In accordance with this, the binary code 100 is used for a run length of four similar adjacent image elements and the code 000011 for a run length of 10. Such a code is particularly suitable for optimizing probability distributions following an exponential descending course.

For reasons of simplicity, representations containing both text information and half-tone images are preferably processed using only one code. In the case of pure texts, a logarithmic code modifiable in accordance with the font, etc. would ensure optimum results. Such a logarithmic code is less favourable, however, for grey-scale images subdivided in accordance with FIGURE 2.

FIGURE 5 is a schematic representation of a simplified subdivision of an image point into individual image point elements in accordance with FIGURE 2.

The image area subdivision of FIGURE 2 permits a more simplified concise representation as each line contains only multiples of two similar adjacent image elements. Therefore, in the representation of FIGURE 5 pairs of adjacent image elements are combined. The first and second image elements in the first line of the image point of FIGURE 2 are combined to form the image element pair A; the third and fourth image elements in the first line of the image point of FIGURE 2 are combined to form the image element pair B, etc. In accordance with this, the image area of FIGURE 5 is made up of 4 lines comprising the image element pairs A and B (first line), C and D (second line), E and F (third line), and G and H (fourth line).

FIGURE 6 shows an arrangement that permits generation of the corresponding image element pair patterns in accordance with FIGURE 5 from predetermined digital grey values I1 to I8. Using a binary code, the parallel transfer of altogether 8 possible digital grey values requires 3 lines 1, 2 and 3. An original image is rather scanned determining for each of the N image areas the appertaining analogous grey value which is then fed in digital form to a shift register 5 via lines 1, 2 and 3. Each stage of the shift register is 3 bits wide to receive a coded group of 3 bits indicative of the assigned grey value. The grey values for successive image areas are fed one after the other to the N shift register stages. The grey value I2 is binary coded as 010; it is assumed to be stored in the bottom-most position of shift register 5. The grey values stored in the individual stages 1 to N in shift register 5 are specified on the left of these stages. The ordinal number (1–N) of the individual image areas

that have already been scanned appears on the right of the various shift register stages. The entry of the grey values into the individual shift register stages is to be regarded as an example only. Thus, the fourth image area has a grey value I5 and the second image point a grey value of the I4. The image point element pair patterns for adjacent line image points are to be generated line-by-line, i.e., in 4 rows according to FIGURE 5. Initially, the image element pair patterns of the first row are generated, then those of the second row, then those of the third row and finally those of the fourth row. Therefore, shift register 5 is designed as a cyclic shift register, since the grey value of an image area is required several times during the generation of the image element pair patterns.

As the grey values for generating the image element pair pattern are required for each of its 4 rows, the contents of the shift register have to be cycled four times via lines 8, 9, 10 from the output of adder 6 to the input of circuit 4. Circuit 4 ensures that the values fed back from the output of the shift register via lines 8, 9 and 10 are returned to the input of the shift register and that this process is repeated altogether 4 times for each image point line. For generating the image element pair pattern of FIGURE 5 from the predetermined digital grey values, an adder 6 and a compare circuit 7 are provided. Adder 6 receives, on the one hand, the contents of a shift register stage and, on the other hand, via line 11, a signal whose value depends on which image element pair A, B, C, D, E, F, G, or H is to be generated from the grey value of the image area. For generating the image element pair A, the value 0 is added to the grey value of the image area, for generating B the value 1 is added to the grey value of the image area, for generating the image element pair C the value 2 is added to the grey value of the image area, etc. The values to be added on line 11 are indicated in brackets behind the image element pairs designated as A to H in FIGURE 5. After the addition, a compare operation is carried out by circuit 7. This compare circuit determines whether the addition result S is smaller than the number of possible amplitude intervals (I1 – I8) + 1, in this case 8 + 1 = 9. If the compare result on line 12 is "yes", the corresponding image element pair is to be printed in black, if not, it is to be printed in white (line 13). In this manner, i.e., by a simple addition followed by a comparison, the grey value of an image area subdivided into individual image element pairs in accordance with FIGURE 5 can be used to determine whether the individual image element pairs A to H are to be black or white. This information is stored and code optimized in accordance with the method described.

In the case of image area subdivisions in accordance with FIGURE 1, for example, or in a manner other than shown in FIGURE 2 in connection with FIGURE 5; the generation of the individual image elements is not as simple as shown in FIGURE 6. In these cases adder 6 and compare circuit 7 would be replaced by a circuit which for each predetermined grey value of an image area, would perform a table look up operation on a store containing the individual image element patterns for the different grey values.

FIGURE 9 is a block schematic illustrating how an image is encoded. Scanner 20 serves to divide the image into image areas by raster scanning. Each image area in the raster scan has its analogue grey value measured by unit 21 and the analogue value is assigned a digital value in unit 22. As explained above, coder 23 receives the digital grey value for each image area and encodes this as a matrix pattern of individual image elements. The image elements are encoded in compressed form by a run-length-encoding technique in compression unit 24. Compressed image data is stored in image store 25 for subsequent use. Either the compressed data can be transmitted in compressed form as a form of facsimile or the compressed data can be expanded to be displayed or printed. Control unit 26, which can conveniently be a suitably programmed computer, controls the various units by means of timing and control signals on lines 27 to 32.

WHAT WE CLAIM IS:–

1. Apparatus for encoding a grey-scale image comprising means for raster scanning the image, means for measuring the grey value of each raster point and assigning to each raster point one of a plurality of digital grey values, means for representing each raster point as a matrix of bits having a bit pattern in accordance with the digital grey value assigned to that raster point, and means for run-length encoding the bit patterns of adjacent scan points.

2. Apparatus as claimed in claim 1, in which each raster point is represented by a 4 × 4 matrix of bits, in which there are 8 digital grey levels including black, and in which the bits are positioned in accordance with the pattern:–

1	5	4	2
3	7	8	6
6	8	7	3
2	4	5	1

wherein black is represented by bits of one value in all positions of the pattern numbered 1 to 8, the first grey level is represented by bits of said one value in positions of the pattern numbered 1, the second grey level is represented by bits of said one value in positions of the pattern numbered 1 and 2, the third grey level is represented by bits of said one value in positions numbered 1 to 3, etc.

3. Apparatus as claimed in claim 1, in which each raster point is represented by a 4 × 4 matrix of bits, in which there are 8 grey levels including black, and in which the bits are positioned in accordance with the pattern:–

8	8	7	7
6	6	5	5
4	4	3	3
2	2	1	1

wherein the black is represented by bits of one value in positions numbered 1 to 8, the first grey level is represented by bits of said one value in positions numbered 1, the second grey level is represented by bits of said one value in positions numbered 1 and 2, the third grey level is represented by bits of said one value in positions numbered 1 to 3, etc.

4. Apparatus as claimed in any of claims 1 to 3, in which said run-length encoding means employs Huffman code to optimize encoding of said bit patterns.

5. Apparatus as claimed in any of claims 1 to 3, in which said image is text, and in which said run-length encoding means employs a logarithmic code to optimize encoding of said bit patterns.

6. Apparatus as claimed in any of claims 1 to 3, in which the image is graphical, and in which the run-length encoding means employs a linear code to optimize encoding of said bit patterns.

7. Apparatus for encoding an image, substantially as herein described with reference to the accompanying drawings.

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Chartered Patent Agent,
Agent for the Applicants.

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1527394 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1

1	5	4	2
3	7	8	6
6	8	7	3
2	4	5	1

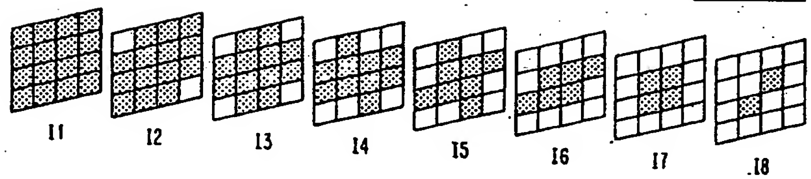
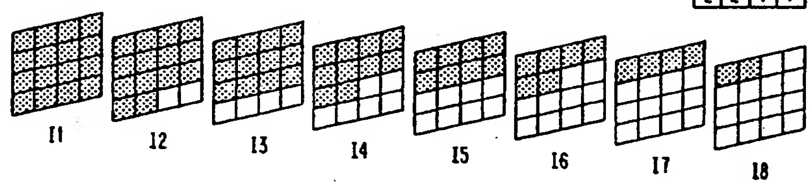


FIG. 2

8	8	7	7
6	6	5	5
4	4	3	3
2	2	1	1



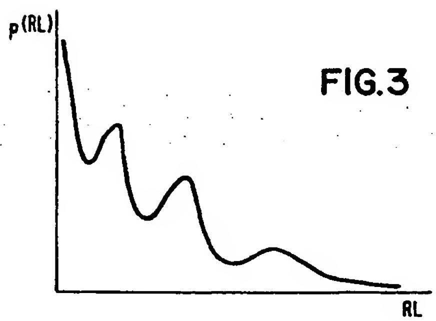


FIG. 3

FIG. 5

A(0)	B(1)	
C(2)	D(3)	
E(4)	F(5)	
G(6)	H(7)	

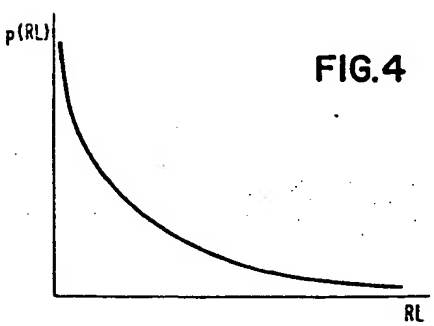


FIG. 4

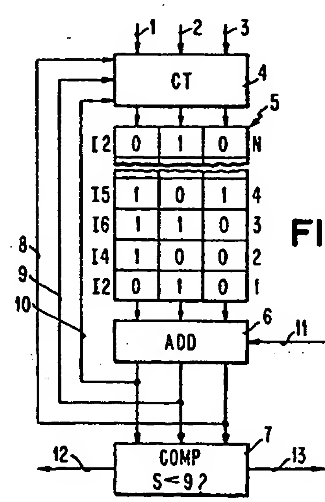


FIG. 6

BNSDOCID: <GB 1527394A I >

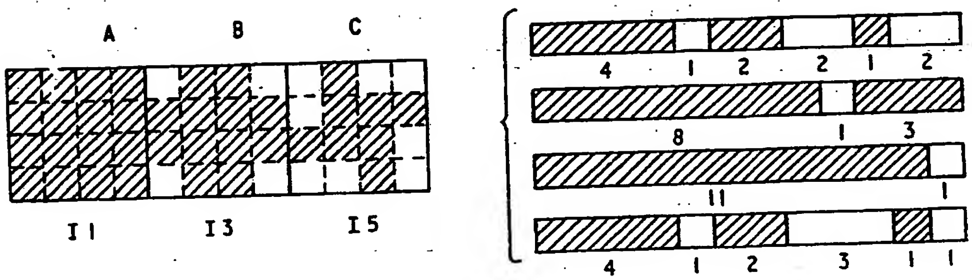


FIG. 7

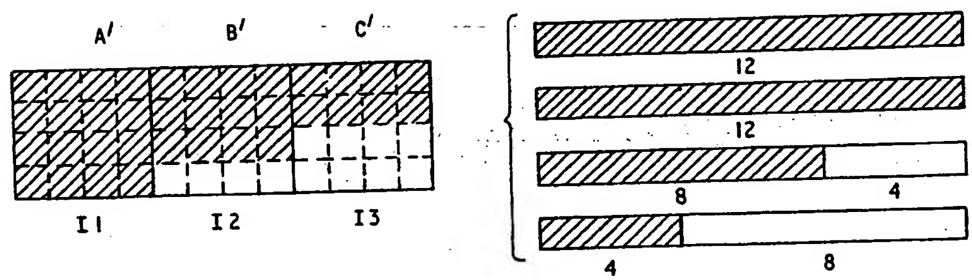
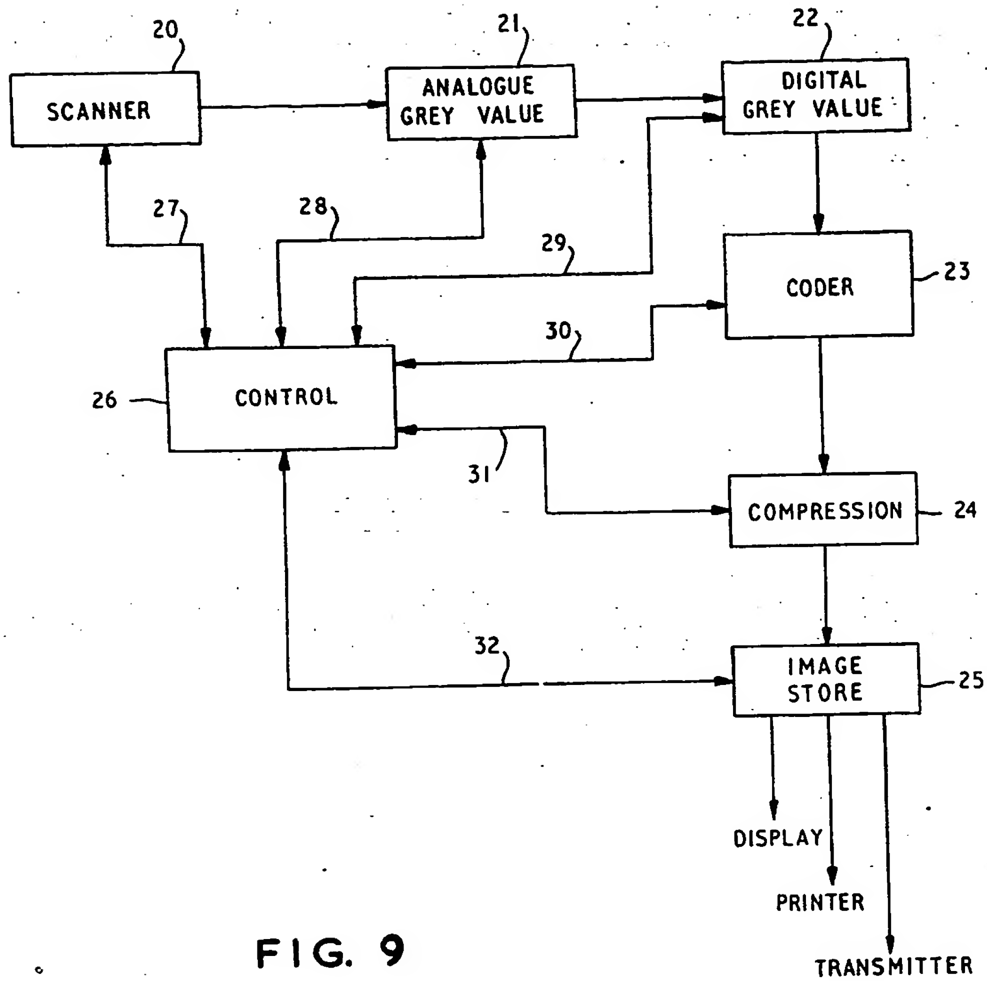


FIG. 8


SCANNER
20
ANALOGUE GREY VALUE
21
DIGITAL GREY VALUE
22
CODER
23
COMPRESSION
24
IMAGE STORE
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CONTROL
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27
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29
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31
32
DISPLAY
PRINTER
TRANSMITTER

FIG. 9

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